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DESCRIPTION

ROLLING BEARING

TECHNICAL FIELD

The present invention relates to rolling bearing and, more in particular, it relates to a rolling bearing which is suitable to a rolling bearing of an extremely reduced size and requiring high rotational accuracy such as for use in spindles of magnetic disk driving devices.

BACKGROUND ART

Inner and outer rings and rolling elements of a rolling bearing undergo repetitive shearing stresses under high surface pressure in the state of use. For enduring such a severe condition in use and obtaining required rolling contact fatigue life, high carbon chromium bearing steels such as SUJ2 were used as steel materials and hardening and tempering were applied after forming to provide a surface hardness HRC of 57 - 64 to inner rings, outer rings and rolling elements.

On the other hand, for HDD used as a memory device for computers, it has been more and more demanded to decrease the size, increase the operation speed and reduce the cost in recent years. For reducing the size of the HDD, decrease in

the size and increase of the density of the magnetic disks have been progressed. In addition, for rotating the magnetic disk at a high speed, it has been demanded for the improvement of the rotational accuracy of rolling bearings for use in spindles.

In order to improve the rotational accuracy of the rolling bearing, it is necessary to decrease residual austenite, which is most deleterious to accuracy characteristics, as less as possible particularly for the raceway surfaces of inner and outer rings. For this purpose, subzero treatment or tempering at high temperature has been applied to the inner and outer rings made of SUJ2 after hardening.

However, although the amount of the residual austenite can be decreased by the subzero treatment after hardening, it is difficult to decrease the content to 0% by volume. Further, while it is possible to decrease the amount of the residual austenite to 0% by volume by tempering at high temperature, since the surface hardness is lowered to about HRC 57 by high temperature tempering, it may be a worry that no sufficient rolling contact fatigue life can be obtained.

Accordingly, when inner and outer rings are manufactured by using SUJ2 as the steel material, it results in a problem that a rolling bearing excellent both in the rolling contact fatigue life and the rotational accuracy can

not be obtained.

As the steel material capable of increasing a surface hardness even applying tempering at high temperature so as to decrease the amount of the residual austenite to 0% by volume, a high speed steel M50 used, for example, in air planes has been known. The high speed steel M50 is a precipitation hardened type alloy steel containing a great amount of Cr, Mo and V and involves a problem in view of acoustic characteristics since macro-carbides larger than 10 μm are present in the formed product after tempering. Further, since the macro-carbides are present already from the stage of blanks, their workability is poor and they involve a problem also in view of the productivity.

Further, steel materials capable of increasing the surface hardness even if the amount of the residual austenite is reduced to 0% by volume by conducting surface hardening treatment such as carburization have also been under development.

However, when the surface hardening treatment is applied to a small sized formed product having a thickness of about 1 mm as in a case of inner and outer rings of a rolling bearing for use in HDD spindles, it is difficult to determine treating conditions or fabrication allowance. Further, since the fabrication cost is expensive, cost is increased.

The present invention has been accomplished while

taking notice on such problems in the prior art and it is an object thereof to provide a rolling bearing excellent both in the rolling contact fatigue life and the rotational accuracy and suitable for use in HDD spindles, at a reduced cost.

On the other hand, in rolling bearings used for precision equipments, the amount of lubricant used has been decreased as less as possible in recent years in order to suppress gases evolved from the inside of the bearing and this brings about a problem of abrasion caused by lubrication failure. As a countermeasure, it has been studied for the use of ceramic rolling elements in order to decrease cohesion between the inner and outer rings and the rolling elements or to decrease the area of contact. However, when the ceramic rolling elements are used, since the contact stress between the inner and outer rings and the rolling elements is increased, it may possibly deteriorate the impact resistance of the bearing.

Another object of the present invention is to improve the impact resistance of a rolling bearing using rolling elements made of ceramics.

DISCLOSURE OF THE INVENTION

For attaining the foregoing objects, the present invention provides a rolling bearing in which at least one of an inner ring, an outer ring and a rolling element is formed

of a steel material containing alloying ingredients within a range of C: 0.80 to 1.20% by weight, Si: 0.60% by weight or less, Mn: 0.25% by weight or less, Cr: 1.00 to 1.50% by weight, and Mo: 0.60 to 1.50% by weight (steel material ①) and then applied with hardening/tempering, the amount of residual austenite is 0% by volume and the surface hardness is HRC (Rockwell Hardness at scale C) of 62 or more.

In this rolling bearing, for the composition of the steel material forming at least one of the inner ring, outer ring and the rolling element, the range of the content for each of C, Si, Mn, Cr and Mo is limited as described above. The critical meaning for the limitation of each of the numerical values is to be described below.

C: 0.80 - 1.20 % by weight

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C is an element for rendering the starting blank into maltensite by hardening/tempering treatment to provide the steel with hardness. If the C content is less than 0.80% by weight, the surface hardness HRC of 62 or more can not sometimes be obtained. If the C content exceeds 1.20% by weight, not only the effect of C for improving the hardness is saturated but also residual austenite tends to be formed.

Si: 0.60% by weight or less

Si is an essential element as a deoxidizing agent in

steel making and also has an effect of increasing the anti-temperability to improve the mechanical strength after the heat treatment and the rolling contact fatigue life. If the Si content exceeds 0.60% by weight, it results in an undesired effect of hindering decomposition of the residual austenite and the machinability is lowered. If the Si content is less than 0.10% by weight, the deoxidizing effect may be insufficient, so that the Si content is preferably 0.10% by weight or more.

Mn: 0.25% by weight or less

Mn, like Si, is an essential element as a deoxidizing effect in steel making and also has an effect of increasing the hardenability to improve the mechanical strength after the heat treatment and the rolling contact fatigue life. If the Mn content exceeds 0.25% by weight, residual austenite tends to be formed and the machinability is lowered. If the Mn content is less than 0.15% by weight, the deoxidizing effect may be insufficient, so that the Mn content is preferably 0.15% by weight or more.

Cr: 1.00 - 1.50% by weight

Cr has an effect of improving the hardenability to improve mechanical strength after the heat treatment and the rolling contact fatigue life. Further, it has an effect of

bonding with C to form carbides and sphericallize cementite. If the Cr content is less than 1.00% by weight, such effects can not be attained substantially. If the Cr content exceeds 1.50% by weight, such effects are saturated.

Mo: 0.60 - 1.50% by weight

Mo is an element for improving the hardenability and increasing the anti-temperability and has an effect of improving the mechanical strength after the heat treatment and the rolling contact fatigue life. For making the surface hardness to HRC 62 or more while reducing the amount of the residual austenite to 0% by volume by elevating the tempering temperature, it is necessary to define the Mo content to 0.60% by weight or more, preferably, 0.80% by weight or more. If the Mo content exceeds 1.50% by weight, not only the effect described above is saturated but also the machinability is lowered. Further, since Mo is expensive, the cost is increased if it is contained by a great amount.

With the definition for the steel material as described above, the surface hardness can be increased as HRC 62 or higher even when the material is hardened at such a high temperature as reducing the amount of the residual austenite to 0% by volume. In addition, since macro-carbides as in the high speed steel M 50 are not present and a surface hardening treatment such as carburization is not necessary

when the steel material as defined above is used, the fabrication cost can be reduced.

Further, if the surface hardness is less than HRC 62, no sufficient rolling contact fatigue life can be obtained and no sufficient impact resistance can be obtained as the rolling bearing for use in HDD spindles.

The present invention also provides a rolling bearing in which at least one of an inner ring and an outer ring is formed of a steel material containing alloying ingredients within a range of C: 0.80 to 1.20% by weight, Si: 0.60% by weight or less, Mn: 0.25% by weight or less, Cr: 1.00 to 1.50% by weight, and Mo: 0.60 to 1.50% by weight (steel material ①) and then applied with hardening/tempering, the amount of residual austenite is 0% by volume and the surface hardness is HRC of 62 or more, and in which the rolling element is formed of a steel material containing alloying ingredients within a range of C: 0.3 to 0.6% by weight, Si: 0.3 to 1.5% by weight, Mn: 0.3 to 1.7% by weight, Cr: 0.5 to 2.5% by weight, and Mo: 0.60 to 3.0% by weight, with the O content being 9 ppm or less, applied with carbo-nitridation and then with hardening/tempering, the amount of residual austenite is 0% by volume and the surface hardness is HRC of 62 or more.

According to this rolling bearing, since the inner ring and/or the outer ring are formed of the steel material

①, amount of the residual austenite of 0% by volume and the surface hardness HRC of 62 or more can be attained without applying a surface hardening treatment, as described above. Further, since the amount of the residual austenite is reduced to 0% by volume and the surface hardness is at HRC 62 or more also in the rolling element, the rolling bearing is excellent both in the rolling contact fatigue life and the rotational accuracy.

In addition, when the rolling element is formed of a steel material with less carbon content and more Mn content than the steel material ① and with low oxygen content (steel material ②) and is applied with carbo-nitridation, since generation of vibrations can be suppressed even during high speed rotation, for example, at about 10,000 rpm to 15,000 rpm, acoustic life at high speed rotation can be increased. For obtaining such effects, it is preferred that the rolling element has a surface carbon concentration of 0.8 to 1.2% by weight and a surface nitrogen concentration of 0.2 to 0.6% by weight. Further, for reducing the amount of the residual austenite to 0% by volume and having the surface hardness HRC of 62 or more, it is necessary to define the Mo content in the steel material to 0.6% by weight or more, preferably, 0.8% by weight or more.

Further, since the rolling element suffers from less deformation by the heat treatment, treatment conditions can

be determined more easily in applying the carbo-nitridation to the rolling element than applying the carbo-nitridation to the inner ring and the outer ring, and the cost can also be suppressed.

Sub C2

In a preferred embodiment of the rolling bearing according to the present invention, at least one of the inner ring and the outer ring is formed of a steel material containing alloying ingredients within a range of C: 0.80 to 1.20% by weight, Si: 0.60%by weight or less, Mn: 0.25% by weight or less, Cr: 1.00 to 1.50% by weight, and Mo: 0.60 to 1.50% by weight (steel material ①) and then applied with hardening/tempering, the amount of residual austenite is 0% by volume and the surface hardness is HRC of 62 or more, and the rolling element is formed of a maltensitic stainless steel, applied with hardening/tempering and then with nitridation to form a nitride layer at a thickness of 3 μm or more on the surface and then finished to a surface roughness of 0. 1μm Ra or less.

Sub C3

According to this rolling bearing, since the inner ring and/or outer ring are formed of steel material ①, the amount of the residual austenite of 0% by volume and the surface hardness HRC of 62 or more can be attained without applying the surface hardening treatment as described above. As a result, a sufficient rolling contact fatigue life and a sufficient impact resistance can be obtained as a rolling

Subb 3

bearing for use in HDD spindles. Further, since the rolling element is formed of a maltensitic stainless steel, applied with hardening/tempering and then applied with nitridation to form a nitride layer at a thickness of 3 μm or more on the surface and then finished to a surface roughness of 0.1 μm Ra or less, the heat resistance and a wear resistance are increased.

Further, by the use of the maltensitic stainless steel as a matrix material for the rolling element, softening of the matrix material upon nitridation can be prevented. Further, in view of the acoustic characteristics and the like, it is preferred to use 13Cr system maltensitic stainless steels. In order that the nitride layer is present uniformly on the surface of the rolling element after the finishing treatment, it is necessary to apply nitridation such that the thickness of the nitride layer is 3 μm or more.

In a preferred embodiment of the rolling bearing according to the present invention, at least one of the inner ring and the outer ring is formed of a steel material containing alloying ingredients within a range of C: 0.80 to 1.20% by weight, Si: 0.60% by weight or less, Mn: 0.25% by weight or less, Cr: 1.00 to 1.50% by weight, and Mo: 0.60 to 1.50% by weight (steel material ①) and then applied with hardening/tempering, the amount of residual austenite is 0% by volume and the surface hardness is HRC of 62 or more, and

the rolling element is formed of ceramics (for example, silicon nitride, silicon carbide, alumina, zirconia and aluminum nitride).

According to this rolling bearing, since the inner ring and/or outer ring are formed of the steel material ①, the amount of the residual austenite of 0% by volume and the surface hardness HRC of 62 or more can be attained without applying the surface hardening treatment as described above. As a result, while rolling elements made of ceramics are used, impact resistance equal with or superior to that in existent rolling bearings (for example, rolling bearings made of SUJ2 for all of inner and outer rings and rolling elements) can be obtained.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a cross sectional view showing an HDD spindle monitor unit incorporated with rolling bearings manufactured as a preferred embodiment of the present invention and put to impact resistance test.

Fig. 2 is a graph showing the result of a heat treatment experiment conducted for deciding heat treating conditions for an inner ring and an outer ring in the preferred embodiment.

BEST MODE FOR PRACTICING THE INVENTION

Embodiments of the present invention are to be described with reference to concrete experimental examples.

First Embodiment

At first, ball bearings each of 5 mm inner diameter, 15 mm outer diameter and 4 mm width, and having a ball diameter of 2 mm were manufactured as described below. The inner rings and the outer rings were manufactured by preparing formed products of a predetermined shape using steel materials for each of the compositions indicated by A - V shown in the following Table 1, then applying hardening at 860℃ and successively applying tempering at 240℃ for 2 hours to each of the formed products. The surface hardness (HRC) and the amount of the residual austenite (γ_R) after the heat treatment are shown together in Table 1. For all of the rolling elements, balls made of SUJ2 used so far were used.

Heat treatment conditions for the inner rings and the outer rings were decided by conducting the following heat treating experiment. That is, after applying hardening at 860℃, and then tempering at each temperatures of 180 to 240℃ to the formed products comprising each of the steel materials indicated by A - P in Table 1 and the value of residual austenite was measured for each of the formed products. The results are shown in the graph of Fig. 2.

As can be seen from the graph, when the tempering

temperature is 230℃ or lower after conducting hardening at 860℃, the value of the residual austenite is reduced to 0 for all of the formed products comprising each of the steel materials indicated by A - P. In this experiment, the tempering temperature was set to 240℃ such that the value of the residual austenite was reliably reduced to 0 in all of the formed products. Further, under the heat treatment conditions, the surface hardness HRC is 62 or more. The heat treatment conditions only show an example and the conditions for the heat treatment conducted according to the present invention are not restricted only thereto.

Then, the ball bearings were assembled into an HDD spindle motor unit shown in Fig. 1 under a pre-loaded state and a test was conducted for examining the impact resistance of the ball bearings.

The HDD spindle motor unit shown in Fig. 1 has a hub 1 that rotates while mounting a magnetic disk, a shaft 2 secured at an upper end to the hub 1, two ball bearings 3 disposed axially, and a housing 4 for rotatably supporting the shaft 2 by way of the ball bearings 3. Each of the ball bearings manufactured as described above was used for the two ball bearings 3 and a pair of identical bearings were combined and assembled between the housing 4 and the shaft 2.

The motor unit was dropped from a predetermined dropping height to exert an impact load of 30 kgf on the ball

bearings 3 and the degree of degradation for the acoustic characteristics before and after dropping was measured. Specifically, axial vibrations (acceleration G value) of the motor unit was measured before and after dropping and it was judged that degradation was recognized in the acoustic characteristic (poor impact resistance: X), when the G value after the dropping was increased by 5 or more than the G value before dropping, and it was judged that no degradation was recognized for the acoustic characteristics in other cases (good impact resistance: ○). The degradation of the acoustic characteristics upon dropping is caused by deformation of the raceway surface of the ball bearing by dropping, and good impact resistance shows that the deformation resistance of the raceway surface is sufficiently high and less tends to cause deterioration of the rotational accuracy. The results are also shown in Table 1.

As can be seen from the result, the ball bearings indicated by A - P in which the composition of the steel material forming the inner ring and the outer ring can satisfy all the relations shown below had the amount of the residual austenite of 0% by volume or less and the surface hardness HRC of 62 or more for the inner ring and the outer rings after heat treatment, so that they were excellent in the impact resistance:

C : 8.0 - 1.20% by weight

Si: 0.60% by weight or less

Mn: 0.25% by weight or less

Cr: 1.00 - 1.50% by weight

Mo: 0.60 - 1.50 % by weight

On the contrary, in the roll bearing indicated by R, since the C content of the steel material forming the inner ring and the outer ring was lower than the range of the present invention, although the amount of the residual austenite after heat treatment was 0% by volume, the surface hardness HRC after the heat treatment was lowered to 60.7 in the inner ring and the outer ring. As a result, the impact resistance was poor.

In the roll bearing indicated by S, since the Si content of the steel material forming the inner ring and the outer ring was higher than the range of the present invention, although the surface hardness HRC after the heat treatment of the inner ring and the outer ring was 62.7, the residual austenite was not completely decomposed even by the high temperature tempering at 240℃. As a result, the impact resistance was poor.

In the ball bearing indicated by T, since the Cr content of the steel material forming the inner ring and the outer ring was lower than the range of the present invention, although the amount of residual austenite was 0% by volume, the surface hardness HRC was decreased as 60.5 after the heat

treatment for the inner ring and the outer ring. As a result, the impact resistance was poor.

In the roll bearing indicated by U, since the Mo content of the steel material forming the inner ring and the outer ring was lower than the range of the present invention, although the amount of the residual austenite was 0% by volume, the surface hardness HRC was lowered to 60.2 in the inner ring and the outer ring after the heat treatment. As a result, the impact resistance was poor.

In the ball bearing indicated by V, a composition corresponding to the SUJ2 steel was used as the steel material forming the inner ring and the outer ring. Since the steel had the Mo content lower than the range of the present invention and the Cr content higher than the range according to the present invention, although the amount of the residual austenite was 0% by volume, the surface hardness HRC was decreased as 57.0 in the inner ring and the outer ring after the heat treatment. As a result, the ball bearing V had poor impact resistance.

As described above, in the ball bearings indicated by A - P corresponding to the examples of the present invention, since the composition of the steel material forming the inner ring and the outer ring is within the range described above, the surface hardness HRC of the inner ring and the outer ring can be increased to 62 or more without applying the surface

hardening treatment such as carburization while reducing the amount of the residual austenite of the inner ring and the outer ring to 0% by volume by high temperature tempering. As a result, ball bearings excellent both in the rotational accuracy and the rolling contact fatigue life can be obtained at a reduced cost.

In the first embodiment, the amount of the residual austenite of 0% by volume and the surface hardness HRC of 62 or more are defined only for the inner ring and the outer ring, but the rolling bearing according to the present invention is not restricted only thereto. That is, for obtaining a rolling bearing excellent both in the rolling contact fatigue life and the rotational accuracy, it may suffice that at least one of the inner ring, the outer ring and the rolling element is formed of the steel material of the composition within the range described above and the amount of the residual austenite of 0% by volume and the surface hardness HRC of 62 or more are attained by hardening and tempering.

Second Embodiment

At first, ball bearings each of 5 mm inner diameter, 13 mm outer diameter and 4 mm width, and having a ball diameter of 2 mm were manufactured as described below. The inner rings and the outer rings were manufactured by

preparing formed products of a predetermined shape using steel materials for each of the compositions indicated by A - P and V shown in Table 1, then applying hardening at 860℃ and successively applying tempering at 240℃ for 2 hours to each of the formed products. The surface hardness (HRC) and the amount of residual austenite (γ_R) after the heat treatment were also as shown in Table 1.

For rolling elements, balls each of 2 mm diameter were prepared by using the steel materials X and Y shown in the following Table 2 and the steel material A shown in Table 1. Subsequently, the ball formed of the material X was applied with carbo-nitridation at 870℃ to 900℃ for 1 to 5 hours, then applied with tempering at 840℃ to 860℃ and, successively, applied with tempering at 270℃ to 350℃ for 1.5 to 3.0 hours. The balls formed of the material Y and the material A were hardened at 860℃ and, successively, tempered at 240℃ for 1.5 to 3.0 hours. The material Y corresponds to JIS steel species SUJ2 steel.

The surface hardness (HRC) and the amount of the residual austenite (γ_R) after the heat treatment of the balls formed of the material X and the material Y are shown in Table 2. Further, the values for the surface hardness (HRC) and the amount of the residual austenite (γ_R) of the materials formed of the material A were identical with those shown in Table 1. Further, the ball formed of the material X

had a surface carbon concentration of 0.9% by weight and a surface nitrogen concentration of 0.3% by weight after the heat treatment.

The inner ring, the outer ring and the rolling elements were assembled in the combination shown in the following Table 3, to obtain ball bearings No. 1 to No. 19. For each of the bearings, the inner rings and the outer rings manufactured of the same material under the same heat treatment were used. The ball bearings were rotated under the following conditions and an acoustic life test was conducted during high rotation.

Rotational Condition

Number of Rotation: 10,000 rpm

Axial load : 2 kgf

Atmospheric temperature: 70℃

Lubricant: mineral oil grease

Rotation time: 3000 hours.

For each of the ball bearings, vibration measurement is conducted just before the start of rotation and just after the end of rotation by an Anderometer. That is, the bearing is attached to the Anderometer and a probe of a converter is brought into contact with an outer ring in a state of rotating an inner ring under a predetermined condition and

applying a thrust load to the outer ring in a stationary state, and a value (Anderon value) in proportion with an effective value of a radial vibration speed caused to the outer ring was measured.

For the judgement of the acoustic life, a value obtained by subtracting an Anderon value just before start of the test from an Anderon value just after the end of the test is calculated as an increased Anderon value. It is judged that the acoustic life is long (○) if the value is 2.5 or less, the acoustic life is somewhat short (△) if it is 5.0 or less and the acoustic life is short (×) if it is 5.1 or more. The results are also shown in the following Table 3.

As can be seen from the result, the ball bearings No. 1 - No. 16 using balls indicated by X in which the composition for the steel material forming the balls (rolling elements) satisfies all the following relations and nitrogen is present on the surface by carbo-nitridation had long acoustic life during high speed rotation.

C : 0.3 - 0.6% by weight

Si: 0.3 - 1.5% by weight

Mn: 0.3 - 1.7% by weight

Cr: 0.5 - 2.5% by weight

Mo: 0.60 - 3.0% by weight

On the contrary, since the ball bearings No. 17 and No. 18 used balls indicated by Y obtained by using the steel material not containing Mo and without applying carbo-nitridation (surface hardness HRC: 57), they had short acoustic life during high speed rotation. Further, since the ball bearing No. 19 used balls indicated by A (balls having a surface hardness HRC at 62.5 by the use of a steel material containing Mo of 1.0% by weight but prepared with no carbo-nitridation), the acoustic life during high speed rotation was somewhat short. The ball bearing No. 19 can provide a sufficiently long acoustic life if the rotation speed is 7000 rpm or less.

<u>Third Embodiment</u>

At first, ball bearings each of 5 mm inner diameter, 13 mm outer diameter and 4 mm width, and having a ball diameter of 2 mm were manufactured as described below. The inner rings and the outer rings were manufactured by preparing formed products each of a predetermined shape by using steel materials indicated by A - V shown in Table 1, then applying hardening at 860℃ and, successively, applying tempering at 240℃ for 2 hours to each of the formed products. The surface hardness (HRC) and the amount of the residual austenite (γ_R) after the heat treatment were also as shown in Table 1.

For the rolling elements, coarse balls each having a diameter of 2 mm or more were formed by using the steel materials a and b with the content of the alloying ingredients having values shown in Table 4, then hardened at 1000℃ to 1100℃ and, successively, tempered at 430℃ - 550℃ for 2 to 4 hours. Then, after grinding the coarse balls to a predetermined size, a gas nitriding treatment was applied at 410℃ to 460℃ for 24 to 48 hours. Then, a finishing treatment was applied to form a nitride layer at a thickness of 15 μm on the surface, to obtain balls each of 2 mm diameter and having a surface roughness of 0.1 μm Ra or less.

The inner rings, the outer rings and the rolling elements were assembled in the combination shown in the following Table 5, to obtain ball bearings Nos. 3-1 to 3-21. For each of the bearings, the inner bearings and the outer rings formed of the identical material and manufactured under the identical heat treatment were used. The ball bearings were assembled under a pre-loaded state to the HDD spindle motor unit shown in Fig. 1, and a test was conducted for examining the impact resistance of the ball bearings in the same manner as in the first embodiment. The results are shown in Table 5.

As can be seen from the table, the ball bearings Nos. 3-1 to 3-16 were excellent in the impact resistance since the inner rings and the outer rings were identical with those of

the ball bearings indicated by A - P in the first embodiment. On the contrary, the ball bearings Nos. 3-17 to 3-21 had poor impact resistance since the inner rings and the outer rings were identical with those of the ball bearings indicted by R - V in the first embodiment.

That is, if the inner ring and the outer ring have the same constitution as that for A - P in the first embodiment, excellent impact resistance can be obtained in the same manner as in the first embodiment using the rolling elements made of SUJ2, even by the use of rolling elements formed of a maltensitic stainless steel, applied with hardening/tempering and then with nitridation to form a nitride layer at a thickness of 3 μm or more on the surface and having a surface roughness of 0.1 μm Ra or less.

Fourth Embodiment

At first, ball bearings each of 5 mm inner diameter, 13 mm outer diameter and 4 mm width and having a ball diameter of 2 mm were manufactured as described below. The inner rings and the outer rings were manufactured by preparing formed products each of a predetermined shape using steel materials indicated by A and V (SUJ2) shown in Table 1, then applying hardening at 860℃ and, successively, applying tempering at 240℃ for 2 hours to each of the formed bodies. The surface hardness (HRC) and the amount of the residual

austenite (γ_R) after the heat treatment were also as shown in Table 1. The rolling elements were formed of ceramics (silicon nitride: Si_3N_4) or SUJ2 as shown in Table 6.

Then, a test was conducted for examining the impact resistance of each of the ball bearings. That is, a procedure of loading an impact load that was increased stepwise on each of the ball bearings and then measuring the acoustic level for each of the ball bearings was repeated and a load at which the acoustic level increased abruptly was defined as an impact resistance load. From the result, relative values with respect to the impact resistance load assumed as 1 for No. 4-3 of the existent example (both inner and outer rings and rolling elements were made of SUJ2) were calculated. The results are shown in Table 6.

As can be seen from the table, in the ball bearings having rolling elements made of ceramics, the impact resistance is reduced compared with the existent example (No.4-3) if the inner ring and the outer rings are made of SUJ2 (No. 4-2) but the impact resistance can be made equal with or superior to that in the existent example (No. 4-3) if the inner ring and the outer ring have the same constitution as that of the ball bearing indicated by A of the first embodiment (No. 4-1).

INDUSTRIAL APPLICABILITY

As has been described above, according to the present invention, rolling bearings excellent both in the rolling contact fatigue life and the rotational accuracy can be provided at a reduced cost by forming at least one of the inner ring, the outer ring and the rolling elements with the steel material as defined above (steel material ①).

Further, a rolling bearing excellent both in the rolling contact fatigue life and the rotational accuracy can be provided at a reduced cost and the acoustic life during high speed rotation can be improved by forming at least one of the inner ring and the outer ring with the steel material as defined above (steel material ①) and using the rolling elements formed with another steel material as defined above (steel material ②) and applied with carbo-nitridation.

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Further, rolling bearings excellent both in the rolling contact fatigue life and rotational accuracy can be provided at a reduced cost by forming at least one of the inner ring and the outer ring with the steel material as defined above (steel material ①), even when rolling elements made of ceramics or rolling elements made of maltensitic stainless steel and applied with nitridation were used.

Table 1

	Content for alloy ingredient (wt%)					Hardness (HRC)	γ_R (vol%)	Impact resistance
	C	Si	Mn	Cr	Mo			
A	1.01	0.11	0.20	1.31	1.00	62.5	0	○
B	0.95	0.30	0.19	1.25	1.01	63.2	0	○
C	0.80	0.35	0.21	1.30	0.97	62.2	0	○
D	1.20	0.11	0.18	1.20	0.98	63.5	0	○
E	1.05	0.15	0.21	1.32	1.01	62.3	0	○
F	1.02	0.11	0.25	1.31	0.95	62.3	0	○
G	1.05	0.12	0.22	1.00	1.02	62.1	0	○
H	1.01	0.11	0.21	1.40	0.95	62.5	0	○
I	1.02	0.12	0.19	1.50	1.01	62.4	0	○
J	1.15	0.10	0.22	1.32	0.60	62.1	0	○
K	1.10	0.11	0.21	1.31	0.80	62.4	0	○
L	1.05	0.12	0.23	1.29	1.50	62.8	0	○
M	1.02	0.11	0.25	1.30	1.05	62.7	0	○
N	0.95	0.12	0.21	1.35	0.95	62.2	0	○
O	0.98	0.50	0.20	1.33	0.98	63.5	0	○
P	1.01	0.60	0.21	1.31	1.02	63.3	0	○
R	0.71	0.12	0.22	1.31	1.01	60.7	0	×
S	1.02	0.82	0.21	1.30	1.05	62.7	3.2	×
T	1.03	0.21	0.23	0.82	1.01	60.5	0	×
U	1.01	0.18	0.22	1.28	0.51	60.2	0	×
V	1.02	0.22	0.24	1.51	—	57.0	0	×

Table 2

	Content for alloy ingredient						Hardness (HRC)	γ_R (vol%)
	C	Si	Mn	Cr	Mo	O		
X	0.4	1.0	0.3	1.5	1.0	9	62～63	0
Y	1.0	0.2	0.2	1.5	—	9	57	0

* O is indicated by ppm and other elements are indicated by % by weight

Table 3

No.	Bearing ring	Rolling element	Acoustic life
1	A	X	○
2	B	X	○
3	C	X	○
4	D	X	○
5	E	X	○
6	F	X	○
G	G	X	○
8	H	X	○
9	I	X	○
10	J	X	○
11	K	X	○
12	L	X	○
13	M	X	○
14	N	X	○
15	O	X	○
16	P	X	○
17	A	Y	×
18	V	Y	×
19	A	Λ	△

Table 4

	Cr	Si	C	N
a	13.2	0.45	0.3	0.14
b	12.8	0.67	0.2	—

(Unit: % by weight)

Table 5

No.	Bearing ring	Rolling element	Impact resistance
3-1	A	a	○
3-2	B	b	○
3-3	C	a	○
3-4	D	b	○
3-5	E	a	○
3-6	F	b	○
3-7	G	a	○
3-8	H	b	○
3-9	I	a	○
3-10	J	b	○
3-11	K	a	○
3-12	L	b	○
3-13	M	a	○
3-14	N	b	○
3-15	O	a	○
3-16	P	b	○
3-17	R	a	×
3-18	S	b	×
3-19	T	a	×
3-20	U	b	×
3-21	V	a	×

Table 6

No.	Bearing ring	Rolling element	Impact resistance
4-1	A	Si_3N_4	1.1
4-2	V	Si_3N_4	0.7
4-3	V	SUJ2	1